

Appendix B
Detailed In Situ Grouting Case Studies

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CASE HISTORIES

The following case studies summarize the work accomplished to date using in situ grouting (ISG) to stabilize or contain radioactive waste sites at U.S. Department of Energy (DOE) facilities.

Oak Ridge National Laboratory Waste Area Group 4, Seeps 4 and 6

In the summer of 1996, the Oak Ridge National Laboratory instituted a project using multiphase, multistage, low-pressure permeation grouting in several unlined radioactive waste disposal trenches located in Brookhaven National Laboratory (BNL) Waste Area Group (WAG) 4. The project was classified as a non-time-critical removal action under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 USC § 9601 et seq.) requirements, but was performed on an accelerated schedule to avoid having to perform work during the Tennessee wet season (ORNL 1997).

Site and Project Background

The BNL WAG 4 is a 9 ha (23-acre) solid waste storage area formerly used for burying radioactive and industrial equipment originating from BNL and other DOE and U.S. Department of Defense facilities. Trenches used for waste disposal in WAG 4 become seasonally inundated with percolating surface water and also are affected by upwelling groundwater. This intrusion of water results in the transportation of contaminants offsite, with some contaminants released in a series of seeps located downgradient from the site.

Waste present in the trenches is highly variable, including absorbent paper, glassware, clothing, scrap metal, filters, lumber, oil, powders, wire, animal carcasses, transuranic (TRU) waste, solvents, and a few large pieces of equipment. Potentially reactive elemental sodium and potassium also may be present in the waste. Contaminants of concern include Sr-90, Cs-137, Co-60, tritium, uranium, thorium, and TRU isotopes, though the principal contaminant of concern is Sr-90 because of its concentration, toxicity, and mobility in the environment. A variety of waste containers (e.g., metal, plastic, wooden, and fiber) were used to contain some types of waste for disposal, but other waste was placed directly into trenches without containers.

Trenches in WAG 4, constructed 100 to 175 ft long, 6- to 12 ft wide, and 12- to 20 ft deep, were excavated through residual soil to weathered shale and limestone. Following placement of the waste, 3 to 4 ft of soil was placed over trenches and some portions of the site were later covered with construction debris. Four trenches were identified as being responsible for approximately 70% of Sr-90 releases from WAG 4 and about 25% of all Sr-90 releases from BNL. To reduce offsite transport of contaminants, grouting was selected to decrease the hydraulic conductivity of waste materials and cause groundwater to flow around rather than through waste materials in the trenches.

Process Description

The technique selected for use at the BNL WAG 4 employed three types of grout: (1) regular cement, (2) ultra fine cement, and (3) acrylamide solution grout. As shown in Figure B-1, grout was injected through sleeve pipes (tube-a-manchettes) driven into areas to be grouted.

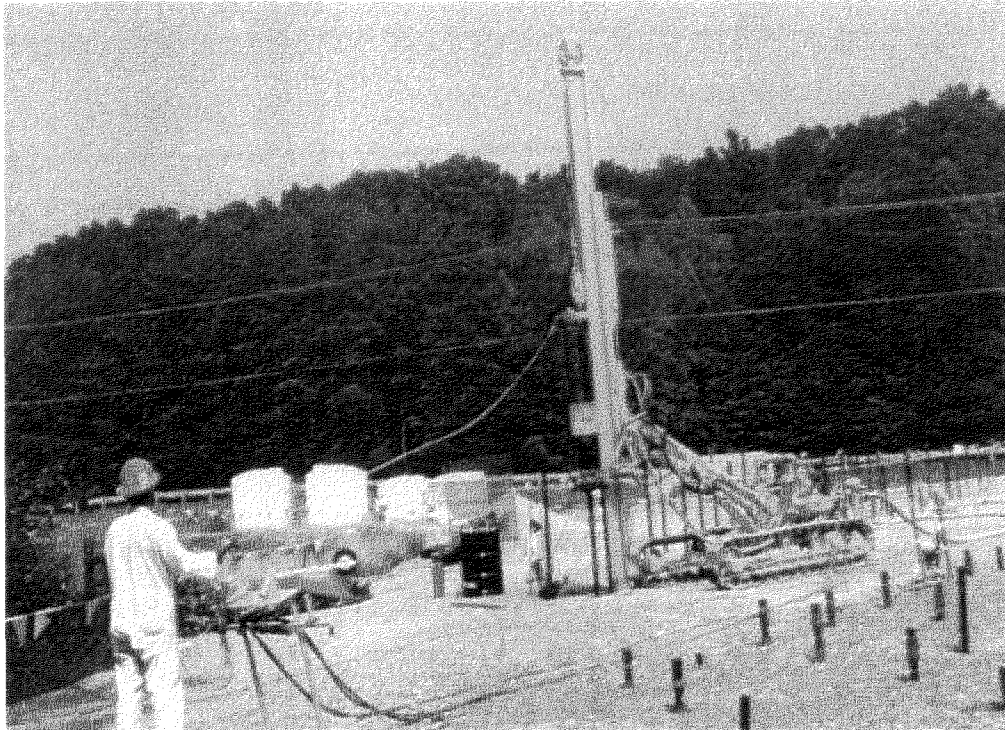


Figure B-1. Grouting Trench 1 at the Oak Ridge National Laboratory (ORNL 1997).

Sleeve pipes were constructed of steel with a minimum 2 in. inside diameter. Grout ports in the pipes were arranged in sets of at least four openings, with a maximum spacing of 20 in. and a diameter of 0.5 in. Grout ports were protected by rubber sleeves that acted as one-way valves allowing grout to flow to the outside while preventing material from flowing in from outside. Sleeve pipes were flushed with water after each application of grout to prevent grout from setting up in the pipe and preventing subsequent application of other grouts.

The project goal was to reduce hydraulic conductivity of waste materials contained in the trenches to a target value of 1×10^{-6} cm/second or less. Because contents of the trenches were unknown and could be highly variable, a variety of grout mixes was used to account for potential differences including, but not limited to, void size, permeability, and amenability to particular grout mixes. Grouts used included regular cement, ultra fine cement, and acrylamide solution. Regular cement-based grouts were used in trench zones where initial in situ hydraulic conductivity was greater than 0.1 cm/second. Ultra fine cement grout was used in those portions of the trench where initial or residual hydraulic conductivity was between 0.1 and 0.005 cm/second. The acrylamide solution grout was used where hydraulic conductivity was less than 0.005 cm/second.

Grout constituents were mixed using a high-shear mixer for cement-based grouts or were metered using a two-piston pump (for the acrylamide solution grout) to deliver components to a static mixer. Constituents used in the grouts are listed in Table B-1.

Table B-1. Oak Ridge National Laboratory Project grout constituents by grout type.

Regular Cement	Ultra Fine Cement	Acrylamide Solution
Type III Portland cement	Ultra fine cement	Activator (triethanol amine)
Bentonite	Bentonite	Initiator (ammonium persulphate)
Water	Water	Inhibitor (potassium ferri-cyanide)
Silica fume	Silica fume	Buffer (sodium bicarbonate)
Natural pozzolan	Natural pozzolan	Dye (used for ease of detection)
Dispersing agent and retarder	Dispersing agent and retarder	
Viscosity modifier	Viscosity modifier	
Class F fly ash		

Results

Trenches were grouted first using regular cement grout followed by applications of ultra fine cement and acrylamide solution grouts. Grout injection pressures were kept low to reduce hydrofracturing and to reduce ground heave. Some hydrofracturing was utilized during all grouting stages, but the hydrofracturing primarily was used to enhance grout that was spread during application of acrylamide solution grout.

Hydraulic conductivity testing calculated the residual in situ hydraulic conductivity for treated trenches and waste. Hydraulic conductivity tests were performed on 23 check pipes.^a Residual hydraulic conductivity measurements ranged from 1.0×10^{-7} to 1.5×10^{-5} cm/second, with a calculated geometric mean of 0.9×10^{-6} cm/second (ORNL 1997).

1987 Idaho National Engineering and Environmental Laboratory Grouting Study

Process Description

In 1987, the Buried TRU Waste Studies Program at the Idaho National Engineering and Environmental Laboratory (INEL)^b evaluated an experimental grouting process developed by Rockwell Hanford Operations. The process was designed to use an I-beam fitted with a central conduit to inject grout into waste pits. The INEL team constructed a simulated waste pit and repeatedly drove the I-beam into the waste using a crane-mounted vibratory hammer. As the beam was advanced, grout was pumped under low pressure through the conduit into waste near the tip of the I-beam. The goal was to reduce the hydraulic conductivity of the site by compacting waste while simultaneously injecting grout.

Results

Researchers were unable to drive the I-beam to the full pit depth. The compaction process caused large holes to develop on the surface of the test pit (cave-ins). Apparently, the overburden soil was being

a. Check pipes are identical to sleeve pipes that are not grouted but located in areas that have been grouted to serve observation and monitoring and evaluation functions.

b. The name for the Site used previous to INEEL.

pushed into the void space in underlying waste containers. Dye material contained in the simulated waste containers, when brought to the surface, had adhered to the I-beam. The hydraulic conductivity, measured as 10^{-4} to 10^{-5} cm/second, was considered unacceptable for treating buried waste. Simulated sludge waste was not well mixed with the grout. Drums penetrated by the I-beam were not completely grouted. A competent monolith was not formed (Loomis and Low 1988).

Idaho National Engineering and Environmental Laboratory Acid Pit

During the summer of 1997, the Idaho National Engineering and Environmental Laboratory (INEEL) performed a CERCLA treatability study of subsurface stabilization. The treatability study was performed in two stages: cold testing in a specially constructed cold test pit and hot testing conducted in the Acid Pit of the INEEL Subsurface Disposal Area (SDA) (Loomis et al. 1998a and 1998b).

Site and Project Background

Located in the SDA, the Acid Pit is a soil area contaminated through past liquid-waste disposal practices with both radiological and hazardous constituents. Liquid-phase acids were dumped directly into the Acid Pit, neutralized by the highly alkaline nature of the soil as well as the occasional addition of unknown amounts of lime. As the pit was filled, soil layers were added until closure when a layer of clean fill was backfilled onto the pit.

The major contaminant present in the pit is mercury at concentrations up to 5,320 ppm. Only minor amounts of man-made radionuclides are present in the pit, with approximately 99% of the contaminants being limited to the bottom 6 ft of the pit.

A small area in the central portion of the Acid Pit, identified during characterization sampling as the region of highest contamination, was selected for the treatability study. Core sampling results suggested that a 14 × 14-ft area centered on the borehole with the highest sampled concentrations of contaminants would best suit the objectives of the treatability study. Contaminants found in the pit included alpha- and beta-emitting radionuclides, metals, nonmetal inorganics (i.e., nitrates and sulfates), and various volatile and semivolatile organic compounds.

A methodical process aided selection of a suitable grout formulation. Previous ISG demonstrations were performed using various grouts and grouting techniques to explore different grout types. These included the following:

- A proprietary water-based epoxy
- An INEEL-developed two-component grout that resembles hematite when cured with soil
- Molten low-temperature paraffin
- A proprietary iron oxide cement-based grout called TECT
- A commercial Type-H high sulfate-resistant cement.

To assist in the preparation for remediation of the Acid Pit, the BNL performed bench-scale tests, including toxicity characteristic leaching procedure. Soil samples were spiked with mercury at concentrations of approximately 1,000 mg/kg. Some grouts, with and without additives (e.g., sodium sulfide), were mixed with the soil samples and tested for effectiveness at binding the mercury contamination. By the end of testing, several grouts had demonstrated the ability to reduce the

leachability of mercury to below instrument detection levels (Loomis et al. 1998b). The TECT-HG^c was selected for treating the Acid Pit. The TECT-HG grout is a cement-based material with high iron oxide content and specially added surfactants and scavengers for mercury contamination.

Process Description

In this process, the drill stem of a jet-grouting rig is drilled into the soil. After the desired depth is reached, grout is injected under pressure. As grout is injected, the drill stem is withdrawn in precise increments, simultaneously rotating and injecting grout through nozzles at the bottom of the drill stem. Changing the operational variables (e.g., withdrawal increment, dwell time at an increment, rotational speed, and grout pressure) creates a column of soil and grout mix. Repeating the process in an approximately triangular pattern on 2-ft centers creates interlocking columns that construct a solid monolith in the treatment zone. The rotating, high-pressure jets of grout mechanically mix the waste soil matrix.

Though the jet grouting technique resulted in minimal grout returns to the surface, earlier studies indicated that some grout returns were inevitable. These earlier studies had employed a specially prepared concrete cap, or thrust block, developed to isolate the drill rig and personnel from potentially contaminated grout returns. The thrust block provided access holes (i.e., 5 in. in diameter and equipped with neoprene material to wipe and clean the drill stem as it was extracted from the ground) for driving the drill stem into the contaminated area, as well as a void space for collecting any grout returns, which allowed work to proceed under clean conditions.

Before the hot treatability study in the Acid Pit, cold testing of the technique was performed in the Cold Test Pit. During this test, grouting operational variables were established. As a surrogate for the Acid Pit mercury contamination, cold testing used molybdenum powder to determine potential for contamination spread through air and potentially contaminated drilling equipment. The cold testing resulted in a variety of recommendations related to the grout application and to other aspects of the demonstration (e.g., redesign of the thrust block to accommodate more grout return flow volume) that were incorporated into the hot test at the Acid Pit.

Preconstructed thrust blocks were delivered to the study staging area, and placed over the area of the Acid Pit to be grouted. Edges were backfilled to lock blocks into place and contain grout returns. Grout was injected using a rotapercussion drill rig and a positive displacement pump for high-pressure injection, as shown in Figure B-2.

The drill was extended through the thrust block and drilled to the designated depth (i.e., to basalt or drill refusal). Grout was delivered through two 3-mm diameter nozzles, located approximately 180 degrees apart and vertically offset by approximately 2 in., and located nominally 6 in. from the bottom of the drill bit. Grout pressures used in the treatability study ranged from 3,500 to 6,000 psi. All grouting was performed at two revolutions per step, a step increment of 5 cm, and a step rate of 2 seconds per step (determined through the cold pit testing).

Results

After the grout was allowed to cure, core samples were taken of the monolith created by the jet grouting. These cores were examined to determine success of the technique, and BNL took samples for analysis.

c. TECT-HG is a low-viscosity grout similar to the TECT grout previously tested but modified with the addition of a mercury-binding agent. It is a proprietary material supplied by Carter Technologies.

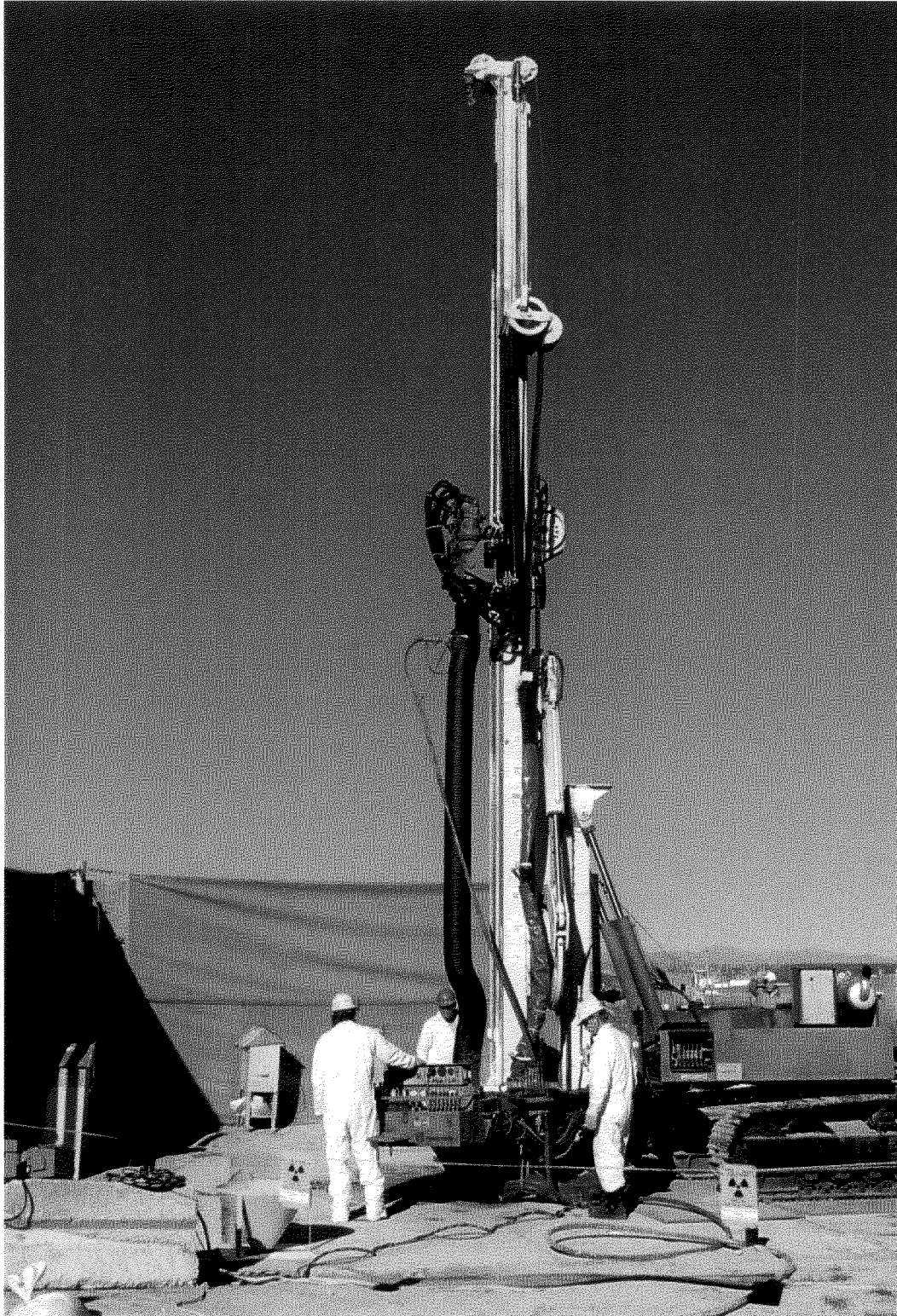


Figure B-2. In situ grouting remediation at the Idaho National Engineering and Environmental Laboratory Acid Pit.

Generally, objectives of the study were met by the grouting technique employed. Results of the treatability study included:

- Hydraulic conductivity of the TECT-HG and soil mixture after treatment was about 1×10^{-11} cm/second.
- Core samples subjected to toxicity characteristic leaching procedure analysis showed leachate concentrations below regulatory levels for all samples.
- The extent of the monolith is verifiable through seismic geophysics techniques that apply to both long and short probes for the geophones.
- The monolith, if necessary, can be retrieved using standard industrial heavy equipment. However, because the matrix has high compressive strength, high force is necessary to break the monolith. Retrieving the monolith from the top down would be impractical, because of its dense nature.
- The jet grouting technique is cost-competitive with other grouting techniques (e.g., soil-auger concept) and other soil-mixing strategies. Jet grouting minimizes spread of contamination in mixed waste sites, particularly when the thrust block is used, and does not present potential hazards associated with using augers and multiple crane manipulations required of soil augering techniques.

Grout returns, shown in Figure B-3, presented one of the major issues associated with using the jet grouting technique. The figure is representative of worst-case grout returns. Because of general lack of void space in soil being treated, grout returns increased and grout deliveries to each borehole decreased as grouting proceeded each day. Early in the day, grout returns were minor despite grouting the entire length of the 10 to 12-ft columns. However, as operations continued, some holes selected previously for grouting were abandoned because of excessive returns. Other potential solutions that were not instituted during this study include grouting in different patterns (e.g., every other hole) or grouting only those regions exhibiting detected contaminants.

Savannah River Site Old F-Area Seepage Basin

Grouting (soil solidification) was the remediation strategy selected in the *Record of Decision for the Old F-Area Seepage Basin at the Savannah River Site* (ORNL 1997). Remediation activities began at the Old F-Area Seepage Basin at the Savannah River Site in 1999 with clearing and chipping of brush in the basin, removing soil from the associated effluent ditch line and basin sidewall, and placing this soil into the basin, to be treated with the rest of the basin soil. Closure activities were completed in June 2000, and the post-construction report was submitted on August 31, 2000 (DOE 1999).

Site and Project Background

From 1954 until 1969, the Old F-Area Seepage Basin at the Savannah River Site served as an unlined seepage basin for reducing radioactive substance concentrations. During its operating life, the basin received wastewater, cooling water, storm water runoff, and spent nitric acid solutions. Wastewater discharges to the basin halted in 1969 after spent nitric acid discharges were received. The Old F-Area Seepage Basin at the Savannah River Site is currently a unit under both CERCLA and Resource Conservation and Recovery Act (42 USC § 6901 et seq.) requirements.



Figure B-3. Excessive grout returns caused by low soil porosity.

The 1.3-acre basin comprises two compartments divided by an interior earthen berm. Ancillary areas associated with the basin include an overflow ditch line and a process sewer line. Radioactive releases during operation of the Old F-Area Seepage Basin at the Savannah River Site are estimated at 1.8 Ci; however, the present inventory is estimated at 0.8 Ci because of radioactive decay. Characterization sampling of the area indicated that soil associated with the basin was impacted by both radiological and nonradiological contaminants, with the primary risk driver being uranium.

Process Description

The technique selected for the Old F-Area Seepage Basin at the Savannah River Site remediation was in situ grouting of the top 2 ft of the basin and soil. Because uranium was the primary risk driver, a Portland cement mixture was selected as the solidifying agent, with fly ash and zeolite additions. The grouting process involved a crane-mounted turntable rotating a specially designed mixing tool. The mix head rotated as it pushed into the soil and pumped the grout through injection points located on the mix head until fluidity was achieved. Soil was mixed to a total depth of 4 to 9 ft to ensure adequate treatment.

Following solidification of the soil, a layer of clean, compacted soil fill was placed over it. Over this layer, the chipped brush (previously removed from the basin and mixed with soil) was compacted into place. A final low-permeability, engineered soil cover was constructed over the basin area to minimize potential radiation exposures and potential impacts on groundwater.

Results

Production grouting of the entire Old F-Area Seepage Basin at the Savannah River Site area was completed in March 2000. A post-construction report was submitted on August 31, 2000.

Hanford Site Close-Coupled Barrier Demonstration

The concept of close-coupled barrier formation is a combination of two jet-grouting techniques developed at BNL and Sandia National Laboratory. Brookhaven National Laboratory was researching and developing polymer grouts for use in subsurface barriers. Sandia National Laboratory was investigating placement methods and cementitious grouts for the same purpose. Discussions held among BNL, Sandia National Laboratory, and grouting contractor Applied Geotechnical Engineering and Construction led to forming a joint venture to explore and develop the close-coupled barrier concept and demonstrate the technology (Heiser and Dwyer 1997).

The close-coupled barrier concept involves taking advantage of the cost benefits of Portland cement-based grouts and performance (low permeability and high integrity) benefits of polymer grouts. Using jet grouting in a close-coupled barrier, a cementitious bathtub is first formed by installing interlocking and overlapping columns of cement-based grout. Within this bathtub, a polymer grout liner then is placed with a dual-fluid jet-grouting technique that binds the polymer barrier to the cement barrier. The resulting containment is a multibarrier system that limits the disadvantages associated with cement grout (i.e., cracking as the result of shrinkage during curing, thermal stresses caused by hydration reactions, and wet-dry cycling prevalent at arid sites) and the high costs associated with polymer grouts.

Site and Project Background

The close-coupled technology was tested in a full-scale demonstration at the Hanford Site. A 5,000-gal steel tank was selected as the demonstration waste form. The tank had been buried in a manner that permitted only the access port in the top of the tank to extend above the ground surface. The goal of the demonstration was to place a close-coupled barrier in a cone-shaped area beneath the tank without disturbing the tank, and then to demonstrate the integrity of the barrier with perfluorocarbon tracers and other geophysical techniques (e.g., ground penetrating radar).

The Hanford Geotechnical Development and Test Facility was the selected location for several reasons. The site is similar to many other DOE sites, fully characterized, free of contamination, close to the grouting subcontractor (Applied Geotechnical Engineering and Construction), and on a low-cost access to instrumentation and equipment for the demonstration. Soil at the site is coarse sand to gravel, and hydraulic conductivity of the site ranges from 10^{-3} to 10^{-1} cm/second (Heiser and Dwyer 1997).

Process Description

Before beginning the demonstration, a test determined the optimal set of parameters for grouting soil in the Hanford Geotechnical Development and Test Facility. Results of this test became the basis for the parameters chosen for the demonstration: a 2.2-mm nozzle diameter, injection pressure of 6,000 psi, two revolutions per step, 5-cm step increment, and a 4.25-second step rate. These parameters resulted in a column of grouted soil that was 30 in. in diameter and relatively uniform in thickness throughout its length. Previous DOE work at INEEL also provided a basis for the grouting parameter settings.

Drilling for the grout column was performed in a circular pattern at a 45-degree angle, forming a cone-shaped barrier. Two rows of columns were grouted at a spacing of 24 in. After the first row of columns was grouted, the second row was formed within the ring of the first columns, touching the first

row. The grouted columns ranged from 26 to 30 in. in diameter, allowing for overlap and interlock of the columns in a honeycomb pattern. The step rate was varied from 4.25 to 3.0 second to minimize grout returns. To further minimize returns and ensure integrity of the second row of columns, the first row was allowed to gel slightly before the second-row grouting began.

The first row of columns was approximately 28 to 30 ft long, leaving a final concrete barrier (approximately 3 ft thick and 41 ft in diameter at the surface) that extended below grade approximately 20 to 21 ft. Cement was allowed to cure for 30 days before verification was attempted with the perfluorocarbon tracer and ground penetrating radar. Tracer testing indicated that the barrier was intact and free of breaches.

Additional tests were performed to optimize parameters for grouting with the polymer grout. Results of these tests influenced the decision to install polymer grout without using drill-stem rotation, resulting in a panel rather than a column. A dual-wall drill stem was used for placement of the polymer barrier to prevent gelling of the polymer inside the drill stem and grout delivery pipes. To conserve grout and minimize overlap of panels at the apex of the cone, the first eight polymer panels were installed every 45 degrees around the barrier and were approximately 30 in. wide and 15 to 16 ft long.

After the first set of panels was allowed to gel, the second set of panels was grouted at bisects of the angles formed by the first set. To account for the convergence of the first set of panels at the apex of the cone, the second set of panels was not drilled as deeply and consequently was shorter (approximately 9 ft long). After these panels had gelled, a final set of panels (approximately 6.5 ft long) was installed to fill gaps between the first and second panels. The final two panels in this last set were not grouted, but the volume of the completed portion was sufficient to contain the tank volume. On completion, the polymer barrier was approximately 34 ft in diameter, 1 ft thick, and covered the inside of the cement grout barrier to a point approximately 3.3 ft from the top of the cement barrier.

Results

In addition to presenting the close-coupled barrier technology, the demonstration also was intended to show the ability of nonintrusive techniques to determine integrity of the placed barrier. Two nonintrusive techniques were tested: perfluorocarbon tracer and ground penetrating radar.

The Hanford demonstration seemed to successfully confirm the ability of the perfluorocarbon tracer to detect breaches in subsurface barriers. However, as the successful barrier emplacement exhibited no large-scale breaches, it was uncertain whether perfluorocarbon tracer could indicate the size or location of breaches. Primarily, the study recommended that tests be performed on barriers with preformed breaches of known location, size, and geometry to confirm the ability of the technology to detect breaches. The study also recommended that further work be done on partial barrier failure (i.e., regions with insufficient barrier thickness) to simulate improper grouting.

Ground-penetrating radar also was studied as a technique to test barrier integrity. Unfortunately, misunderstandings about the barrier construction and interference from the steel tank limited usefulness of the ground-penetrating radar evaluation results. Despite these problems, ground-penetrating radar was generally believed to be useful in verifying the horizontal extent of grout injections and was considered potentially useful for finding gross deficiencies (e.g., missing columns) in the barrier.

Visual examination of the barrier after excavation confirmed that the barrier was completed as planned. The barrier showed no signs of breached areas or leak pathways—both the polymer layer and the upper (excavated) portion of the cement layer were continuous and breach free. Several small gaps in the outer ring of cemented columns were noted, but the inner layer of columns was continuous. The one

observable flaw was that the conical nature of the barrier resulted in columns overlapping at the apex of the cone. This overlap measurably reduced the inner volume of the cone and indicated that much of the cement grout (either within the cone or at the exterior of the apex below the bottom of the barrier) was wasted.

Measurements of barrier permeability were made after the tank and soil within the barrier were excavated and removed. Mean field-saturated hydraulic conductivity for the Portland cement and sand barrier was determined to be 1.7×10^{-8} cm/second and 3.0×10^{-9} cm/second for the polymer and sand barrier. However, these measurements were taken with a Guelph permeameter with a manufacturer's specification range of only 1.0×10^{-6} cm/second. Subsequently, the only definitive conclusion that could be made was that the hydraulic conductivity was less than 10^{-6} cm/second.

Core samples from the cement and polymer layers, taken from different locations throughout the barrier, were analyzed for various characteristics. Hydraulic conductivity measurements ranged from 1.9×10^{-9} to 6.3×10^{-10} cm/second, with an average of 2.4×10^{-9} cm/second. Homogeneity of the grouted barrier was estimated from density measurements taken from core samples. For the polymer grout, densities ranged from 1.95 to 2.04 g/cm³, with a mean value of 2.01 ± 0.03 g/cm³. Cement grout density averaged 2.01 ± 0.05 g/cm³. Grout samples also were examined visually and appeared to be well mixed and void free.

Hanford's location in a semiarid region with low soil moisture content led to the decision to perform wet- and dry-cycle testing to determine the effect, if any, on barrier materials. Polymer and cement core subjected to 12 wet-dry cycles exhibited no visible degradation. Weight changes for the polymer grout and soil samples were minimal, with an average weight change for three samples of 0.07% from the initial pretest weight to the final dry-cycle weight. Weight changes for the cement grout and soil core samples were higher than for the polymer and soil cores. From the initial pretest weight to the final dry-cycle weight, the average percent weight change for the two cement grout cores was 1.6%.

Brookhaven National Laboratory Glass Hole Waste Site Remediation Technology Demonstration

After successfully demonstrating the close-coupled barrier technology at Hanford, the technology was implemented in a full-scale demonstration at the Glass Hole Waste Site, located in Operable Unit 1 at the BNL. Unlike the selected Hanford demonstration site, the Glass Hole Waste Site was an actual remediation site. However, the BNL demonstration was not intended as a final remedy for the waste site, but as an interim measure to contain constituents in the pit for eventual final remediation (Heiser and Dwyer 1997).

Site and Project Background

From the 1960s through the early 1980s, the Glass Hole Waste Site was used for disposing of contaminated glassware and chemicals generated through laboratory operations. In the Glass Hole area, 17 individual pits were excavated with a clamshell. These unlined pits are approximately 10 to 15 ft in diameter and 10 to 15 ft deep and received waste materials and backfill, then a final backfill to bring each closed pit to grade level. Incomplete record keeping on the location, number, and contents of the waste pits made it difficult to determine a remedial design.

The demonstration site is referred to as Glass Bottle Pit G-11. Originally believed to consist of two nearly connected pits, this site later was found to include only a single pit, located in glacial deposits of fine- to coarse-grained quartzose sand with lesser amounts of gravel. A 1-ft layer of quartz stone cobble

ranging from 1 to 3 in. lies approximately 5 ft below the surface. Groundwater in Operable Unit 1 is contaminated with volatile organic compounds, heavy metal(s), and fission products, but the exact origin of these contaminants remains unknown.

Process Description

The process for installing the close-coupled barrier at the BNL was used previously at Hanford, with the exception that a V-trough shape was chosen to avoid duplicating Hanford's problem with excess grout at the cone's apex.

Type I Portland cement was chosen as the grout type. The grouting parameters determined for installing the cement barrier specified a 2.2-mm nozzle opening, 6,000-psi grouting pressure, two revolutions per step, a step increment of 5 cm, and a step rate of 4.25 seconds. These parameters formed columns of cement grout approximately 26 to 30 in. in diameter.

Vertical walls at the end of the trough were installed first. Because spoils return was slightly higher at BNL than at Hanford, alternating holes were grouted in each row to eliminate cross-communication between the columns. A 21-in. center-to-center separation of the columns was used, and to further limit spoils production, the first row of columns was allowed to cure slightly before grouting in the second row. Because each row required 17 columns, each vertical wall required 34 columns.

As shown in Figure B-4, installing angled walls involved drilling at a 45-degree angle, using the same parameters and techniques selected for the vertical walls. These angled walls met the vertical walls 5 ft below grade to form the trough. These techniques formed a barrier that extended 26 ft below grade and was 42 ft long, 30 ft wide, and approximately 3 ft thick. The contained area was 36 ft long, 24 ft wide, and 18 ft deep.

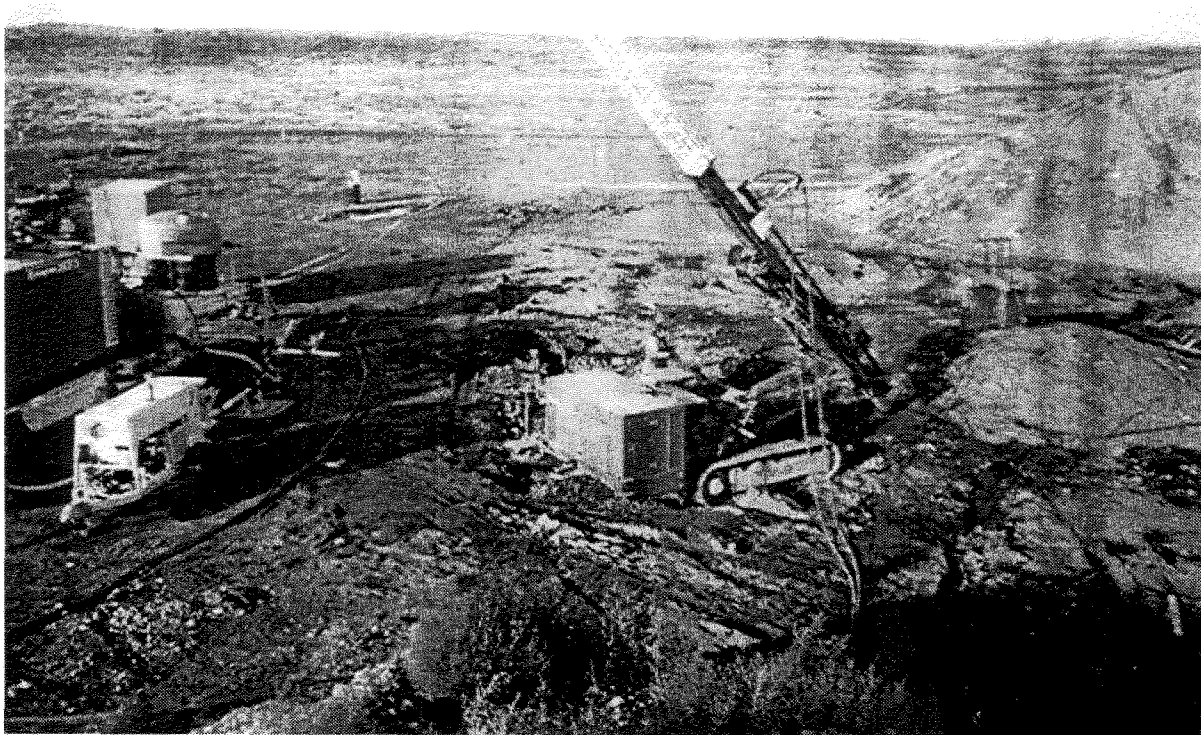


Figure B-4. Angle grouting at Brookhaven National Laboratory (Dwyer et al. 1999).

After the cement barrier was in place, the polymer layer was grouted in place using the dual wall stem. Overlapping panels were laid along the bottom 6 ft of the trough, forming a very low-permeability, chemically resistant zone approximately 12 in. thick, with enough volume to contain the entire liquid content of the pit. Angled walls were placed first, followed by the vertical walls.

Because the barrier was intended for interim use only (3 to 5 years), the polymer selected was AC-400, a two-part acrylate gel polymer. Both pumps of the two-part system maintained a pressure of 1,000 psi for grout installation, withdrawal rate was kept constant to minimize spoils returns, and gel time was adjusted to 30 minutes to prevent run-out in coarse sand found at the site. The drill stem was not rotated, which resulted in formation of panels. To provide sufficient panel overlap and form a continuous barrier, panels were placed every 21 in.

After verifying integrity of the close-coupled barrier using perfluorocarbon tracer, contents of the Glass Bottle Pit were jet grouted with a cement grout. Plastic sheet piling was placed around the waste pit, internal to the V-trough, to form a vertical rectangular wall around pit contents. Columns were placed on 21 in. centers until the entire interior of the sheet piling-delineated area was solidified. Spiral wound tubing was inserted vertically through the entire height of the grouted monolith so that the array of tubes outlined 4×4 -ft cells. U-shaped reinforcing rods also were set in the cells to serve as lifting attachments during eventual retrieval of the monolith. These features of the close-coupled barrier and waste-grout monolith are pictured in Figure B-5.

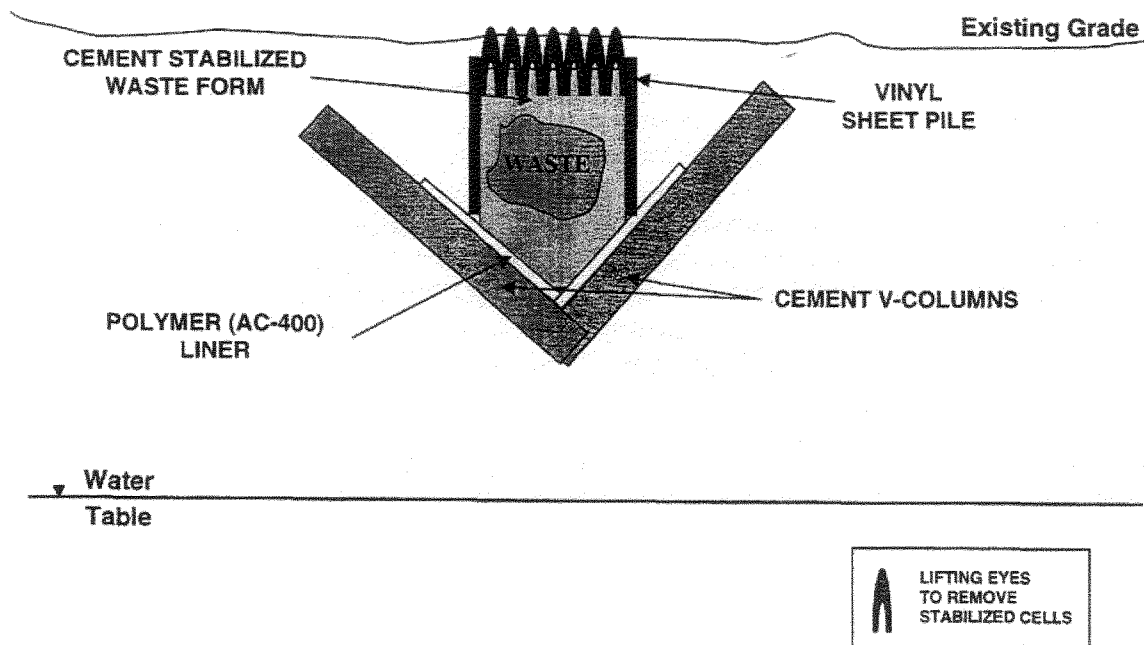


Figure B-5. Schematic of the close-coupled barrier combined with grout monolith at Brookhaven National Laboratory (Dwyer et al. 1999).

After the monolith had cured for several months, BRISTAR demolition grout^d was placed into the spiral-wound tubing. The combination of the BRISTAR grout and the tubing, which tends to unwind during expansion and put tension on the monolith, served to fracture the monolith into individual 4 × 4-ft cells, enabling retrieval.

Results

Perfluorocarbon-tracer testing of the barrier demonstrated that placement of the close-coupled barrier successfully confined waste. Perfluorocarbon testing indicated no large-scale breaches in the barrier. This was later supported when the pit was excavated for retrieval of waste contents. At the time of the 1997 Heiser and Dwyer report, the laboratory had not yet completed testing core samples taken from the barrier. However, hydraulic conductivity for cores taken from the cement layer ranged from 1.1×10^{-6} cm/second to 1.6×10^{-8} cm/second and averaged 3.4×10^{-7} cm/second.

Using BRISTAR grout to section the grouted pit monolith did not prove as effective as anticipated. After dirt had been removed from the top and from inside the barrier adjacent to the monolith, it could be seen that cracking was not as extensive as originally thought. Eventually, a backhoe completed the demolition process by breaking the cement waste form into smaller pieces. Subsequently, it was recommended that such demolition grout not be used for future waste form sizing.

Idaho National Engineering and Environmental Laboratory Fiscal Year 1994 - Innovative Grout Retrieval Demonstration

During FY 1994, the INEEL performed an innovative retrieval demonstration combining jet grouting and monolith retrieval. The demonstration focused on the following goals:

- Using jet grouting to solidify contents of a simulated buried waste pit
- Applying a demolition grout to size the resultant monolith into retrievable portions
- Retrieving the fractured pieces with remotely controlled heavy equipment (Loomis and Thompson 1995).

Project Background

The INEEL constructed a simulated waste pit with 55-gal steel and cardboard drums and cardboard boxes filled with simulated waste items, including sludge (i.e., canola oil and a mixture of absorbents), cloth, paper, wood, metal, and concrete. A rare earth tracer simulated TRU contamination in waste and potential contaminant releases during operations. These simulated waste items were placed randomly in the pit, then backfilled with soil typically used in the nearby SDA for actual waste burials. A weather shield erected over the cold pit helped eliminate the potential for extraneous air currents during air sampling to determine contaminant release.

Process Description

Five holes outside the demonstration area were jet grouted to determine grouting parameters before the actual demonstration began. The first two holes were grouted with a 1:1 mixture of Portland cement and water based on volume; however, low viscosity of this mix resulted in unacceptably high grout

d. A fast curing expansive grout used to fracture rock and concrete structures.

returns. Grout for the other three holes was formulated with a 1:1 ratio of Portland cement and water based on mass, which resulted in fewer grout returns. During grouting of the last three holes, injection pressures and drill stem withdrawal rates were varied to determine the optimal set of parameters for the actual demonstration.

Trial holes also were used to evaluate the option of inserting 2-in. thin-walled, spiral-wrapped tubing (for later application of the demolition grout) into holes immediately after grouting was complete. In the event that spiral-wrapped tubes could be placed before grout had set, the need to drill holes into the hardened monolith (a time-consuming operation that could result in dust release) could be eliminated.

After the demolition grout tests and destructive examination of five test columns were complete, the entire simulated waste pit was grouted with Portland cement grout. Grouting parameters specified a grouting pressure of 6,000 psi, a step interval of 5 cm, two revolutions of the drill stem per step, and a step rate of 6 second. Grouting began after the drill stem had been inserted 12 ft into the simulated waste pit, and stopped at approximately 4 ft below ground surface (or immediately, if large amounts of grout exuded from the top of the pit). After each hole had been grouted, the drill stem was removed and the thin-walled, 2-in., spiral-wound tubing was inserted into the soft grout. Grout holes were drilled in an alternating triangular pattern that skipped to different areas of the pit to minimize grout returns through adjacent holes.

Thirty-six holes on approximately 2-ft centers were grouted over the course of 3 days during treatment of the test pit. Grout returns totaled approximately 1 yd³, with large amounts of grout returning from two holes. These large returns were attributed to the presence of sludge containers near the grout holes. Sludge drums were characterized by poor mixing and extremely fine void spaces, resulting in sludge being displaced by incoming pressurized grout.

The BRISTAR demolition grout was applied in two formulations: BRISTAR 100 (with an applicable temperature range of 60 to 95°F) and BRISTAR 100S (with an applicable temperature range of 96 to 122°F). Tests were performed on each formulation to determine the temperature range required for application. Grout must be applied to the monolith before it has cooled completely. Hydration reactions in the curing cement raised the monolith's temperature to as high as 140°F, and insulating properties of surrounding soil prevented the block from cooling in a timely manner. After excessive temperatures caused a series of small steam explosions (blowouts), all spiral-wrapped tubes were filled with higher temperature-range BRISTAR to complete the fracturing part of the demonstration.

Results

No upward movement (heaving) of the surface was noted during the grouting demonstration. Grout returns were not considered excessive, except as noted above. No contaminant spread was noted during drilling and grouting operations.

Visual inspection of the monolith (conducted after the demolition grout application) found considerable cracking and expansion of the thin-walled tubes on top of the pit. Cracks up to 1 in. wide were visible in soil on top, leading to the conclusion that demolition grout had been effective in fracturing the monolith.

However, when the monolith was retrieved, virtually all of the tubes in the monolith's interior had failed to expand, resulting in no fracturing. Subsequent reapplication of the BRISTAR had a much greater effect in fracturing solidified cement grout and waste. Subsequent tests performed on thoroughly cooled waste led to the conclusion that temperature gradations had prevented proper action of the BRISTAR.^e

e. Regions near the edge of the monolith were much cooler than the interior, and using a demolition grout formulation applicable to interior portions in the monolith was ineffective in cooler portions.

Retrieval operations were performed in two phases: (1) an initial phase where soil overburden was removed as the monolith was fractured and removed and (2) a second phase during which the overburden was removed before retrieving the remaining monolith. In both phases, cement grout was found to have done an excellent job in encapsulating and solidifying the simulated waste. As shown in Figure B-6, examining the simulated waste pit verified that waste containers had been penetrated and their contents grouted.



Figure B-6. Penetrated simulated waste containers with grouted contents.

Two major test goals were (1) examining potential release of contamination during grouting activities and (2) demonstrating the effectiveness of grout in preventing release of contamination. Eight high-volume air samplers placed at various locations inside the weather shelter collected data during various phases. Evidence of tracer movement during the grouting phase was virtually nonexistent, even

during grouting of holes where excessive grout returns were noted. This indicates that the tracer was locked into the grouted matrix and not released by the drilling and grouting.

Tracer spread was extensive during retrieval activities, involving simultaneous removal of the overburden and monolith. When retrieval started after the overburden had been removed, much less tracer spread was noted, a reduction attributed to overburden soil falling onto waste items in the bottom of the pit. The retrieval process exposed the face of the monolith. As digging tore open waste containers (which would be encased in grout), waste items (particularly paper) tumbled to the bottom of the pit. Soil falling onto this paper presumably caused the dust and tracer to become entrained. This assertion was further supported by variations in airborne dust and tracer resulting from different backhoe operators with different techniques (i.e., methodical versus hurried) for retrieving waste.

Idaho National Engineering and Environmental Laboratory Fiscal Year 1995 - Innovative Subsurface Stabilization Project

In FY 1995, the INEEL performed a series of applied research tests of jet-grouting techniques for stabilizing simulated buried waste pits. These tests involved using different types of grouting materials meeting appropriate grouting criteria to (1) determine the implementability of using jet grouting to form monoliths out of buried waste material, (2) identify suitable grout agents, and (3) establish basic hydraulic conductivity data for both grouted and ungrouted buried waste sites (Loomis, Zdinak, and Bishop 1997). The evaluation involved examining jet groutability, the extent of waste encapsulation, the monolithic nature of grouted pits (defined through both destructive examining and coring), hydraulic conductivity of buried waste, and comparison of hydraulic conductivity of grouted values to ungrouted values.

Site and Project Background

The project was completed in four phases:

1. Constructing simulated four waste pits and three field-scale permeameters for the tests, jet grouting of test pits and one field permeameter
2. Coring grouted permeameters and test pits
3. Destructive examination of test pit monoliths
4. Hydraulic conductivity testing of ungrouted field permeameter and grouted permeameter.

The 6 × 6 × 6-ft test pits contained simulated waste containers consisting of bagged waste and 30-gal metal and cardboard drums. (The size of the pits would not accommodate standard 55-gal drums.) The field permeameters were 10-ft diameter concrete culverts, 10 ft deep, containing simulated waste in 55-gal drums in random orientation. Simulated waste materials included cloth, blotter paper, wood, metal, nitrate salt simulator (sodium sulfate), inorganic sludge simulant (INEEL soil), and organic sludge simulant (canola oil and absorbents). Rare earth tracers (e.g., cerium oxide) were placed in 55-gal drums in the permeameters to monitor potential movement of simulated waste constituents. Pits and permeameters were filled with soil after the simulated waste containers had been placed.

Process Description

This test was conducted with the standard INEEL rotary-point injection-grouting equipment. During the process, a modified well and coring drill rig drove an approximately 5-in. diameter drill stem into waste. The subassembly consisted of two nozzles, 180-degrees opposed, approximately 18 in. from

the cutting tip. A high-pressure positive displacement pump supplied grout to the drill stem and jet nozzles. During the actual test, simulated waste drums and debris were penetrated without difficulty.

The demonstration applied four different grouts:

- A paraffin that melted at low temperature (Waxfit 12)
- An INEEL-developed iron oxide grout (Artificial Hematite)
- A proprietary iron-oxide cement (TECT)
- An organic water-based epoxy (CARBRAY 100).

Only one field permeameter was grouted with Type-H Portland cement. The second of three permeameters was constructed, but not filled with soil or waste because of budget considerations, and the last permeameter was used to measure hydraulic conductivity under normal soil and waste conditions.

All grouting of test pits was performed with a nominal pressure of 6,000 psi and used a thrust block to contain any grout returns. Details about the grouting phase of the test follow:

- **TACT grout:** Eleven holes were jet grouted in 81 minutes (7.3 minutes per hole average). Grouting parameters included a 5-cm step interval, two revolutions per step, 3-mm nozzle jets, and a step rate of 6 seconds. Field tests conducted in accordance with these parameters produced a grouted column 24 in. in diameter. The thrust block contained minimal grout returns during the demonstration.
- **Paraffin grout:** Paraffin in a molten form at 140°F was jet grouted with a 2-second step rate, a step interval of 5 cm, 2.3-mm nozzle openings, and two revolutions per step. Fifteen holes were grouted in 99 minutes, for an average of 6.6 minutes per hole. Grout returns, characterized as copious, were attributed to cross-communication between holes. Though the thrust block was not able to contain these grout returns, they were managed by directing molten paraffin to a spoils-collection pit.
- **INEEL-developed hematite grout:** An unsuccessful attempt was made to jet grout a test pit using the INEEL-developed grout with available delivery systems (CASA GRANDE Jet 5 pump and Schwing pump). The grout, a two-part mixture, was designed to be injected with a dual-wall drill stem. However, difficulties were encountered when one part of the grout plugged the nozzle. Attempts to use this grout were abandoned.
- **Epoxy grout:** An unsuccessful attempt was made to grout the two-part water-based epoxy with the dual-wall drill stem. Viscosity problems with one part of the formulation (exacerbated by adding water to dilute the solution) proved insurmountable, and the epoxy was not used.
- **Type-H Portland cement:** After epoxy was abandoned, efforts moved to the fourth test pit. It was successfully grouted with type-H Portland cement (mixed 1:1 with water by mass), in accordance with the following parameters: 5-cm step interval, 6-second step rate (later changed to 5 seconds, 4 seconds, and finally 3.5 seconds), 2.3-mm nozzles, and two revolutions per step. During this demonstration, 19 holes were grouted in 1 hour and 59 minutes (6.3 minutes per hole average). The thrust block contained minimal grout returns. The field permeameter was grouted with type-H Portland cement (mixed 1:1 with water by volume), at 6,000 psi, with a 2.2-mm opening, 5-cm step interval, two revolutions per step, and a step rate for most holes of 6 second (depending on grout returns). Twenty-seven holes were grouted during a 2-day period, and that included time to set up

and drill each hole. Holes for grouting were drilled 11 ft 8 in. into the permeameter, and the bottom 9 ft 3 in. was grouted. A thrust block was not needed or used, as grout returns were directed into a spoils pit. The confined nature of the permeameter apparently caused heaving of the top surface.

Results

Four cores of the field permeameter and at least two cores of each grouted pit were removed with a 2.4-in. inner-diameter coring tool. Test pit cores were taken in a manner that permitted the coring tool to collect and penetrate each different simulated waste form in the pit. Cores were examined visually and filmed using video logs to determine the extent of grout pervasiveness and structural integrity of the monoliths. Core holes then were used as access holes for later hydraulic conductivity testing (i.e., packer testing). After sufficient curing time, test pits also were destructively examined with a standard backhoe.

Hydraulic conductivity testing (packer testing) was conducted on all grouted pits and the grouted permeameter. Results of packer testing on the TECT and paraffin pits showed less than 10^{-7} cm/second conductivity. Conversely, the type-H cement pit was extremely porous, with hydraulic conductivity of 10^{-3} to 10^{-4} cm/second. Though the field permeameter, also grouted using type-H Portland cement grout, showed considerable cross-communication between holes, conductivity of 10^{-7} cm/second was measured in several positions.

The jet grouting solidified the cement pit into a monolith despite evidence that injectors had plugged during the grouting process, a phenomenon also noticed when examining the cores. In some cases, simulated nitrate salts (sodium sulfate) were poorly mixed and resulted in a porous area that became a pathway for water during the hydraulic conductivity testing.

The TECT and paraffin pits showed a relatively solid matrix during examination of core samples. The Type-H Portland cement grout, in both the test pit and the field permeameter, showed less integrity. The TECT pit had core recoveries ranging from 82 to 100% for three cores. The paraffin pit showed core recoveries of 100% in both cores. Core recoveries from the Type-H Portland pit were poor, ranging from 55 to 64%.

Both the TECT pit and paraffin pit demonstrated that the variety of waste types were mixed and encapsulated by the grout monolith. The steel drum bodies were penetrated and the contents mixed as the injection nozzles were withdrawn through the drum contents. Even problematic waste streams such as simulated Series 743 sludge drums (as shown in Figure B-7) were effectively encapsulated with grout.

Destructive examination of the paraffin pit was accomplished easily using the backhoe. Dust spread was minimal owing to the permeation of simulated waste materials and soil by paraffin. Even a drum of simulated organic sludge was solidified (to a lard-like consistency) to permit its retrieval using hand tools. Presumably, the time required for paraffin to cool was sufficient to allow its permeation into waste materials.



Figure B-7. Effective grouting results for simulated oil sludge at the Idaho National Engineering and Environmental Laboratory.

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